Long-Term Economic Simulation: Even-Aged and Uneven-Aged Examples from the Missouri Ozark Forest Ecosystem Project (MOFEP)

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ABSTRACT: *Much of the software and many of the algorithms commonly used to simulate forest growth and harvesting activities have been optimized for short-term projections based primarily on larger-sized trees and are focused on even-aged silvicultural systems. Using data on trees 1.5 in. dbh and larger from the Missouri Ozark Forest Ecosystem Project (MOFEP), we have adapted the widely available Landscape Management System (LMS) and Forest Vegetation Simulator (FVS) software to make long-term simulations using even and uneven-aged silvicultural management systems. MOFEP is designed to test the long-term effects of even-aged, uneven-aged, and no harvest treatments on a variety of ecosystem attributes. To simulate the economic outcomes of these three treatments, we have written new LMS algorithms that simulate the effects of uneven-aged harvesting. Our results show that in the Missouri Ozarks even-aged and uneven-aged management silvicultural systems yield long-term (100 years) economic outcomes that are not statistically different. This result reinforces the need for land managers or landowners to consider esthetics, nontraditional forest products, and other nonmarket values in their decision matrix. North. J. Appl. For. 22(1):42–47.*

Key Words: Growth and yield simulation, forest economics, even-aged management, uneven-aged management.

The Missouri Ozark Forest Ecosystem Project (MOFEP), initiated in 1989 in southeastern Missouri, is a 9,200-ac landscape experiment designed to compare the impacts of even-aged, uneven-aged, and no harvest management on a wide array of ecosystem components over a 100-year period (Figure 1). Each of the three treatments was replicated on three sites, and each site was a minimum of 600 ac in size, contiguous with minimal edge, largely free from manipulation for the past 40 years, or longer if possible, owned by the Missouri Department of Conservation (MDC), located in the southeastern Missouri Ozarks, and relatively close to each other (Brookshire et al. 1997). That the areas were free from manipulation allows us to more confidently attribute differing outcomes to the treatments not to past history.

One of MOFEP's objectives is to test the long-term sustainability of these silvicultural systems. Although MOFEP is primarily focused on biological sustainability, that sustainability, if it is to be applicable to nonexperimental forest management must include financial feasibility over the same long-term period. Among the essential requirements for timber yield sustainability are age and diameter class structure and growth rates that allow for approximately equal periodic yield of products of desired size and quality. Financial feasibility is achieved for any outcome with a positive financial return, but landowners and forest managers concerned primarily with financial returns will be interested in the treatment with the highest overall return. Managers and landowners concerned with net benefits to society, themselves or their heirs, will still include financial benefits in their overall cost/benefit analysis.

MOFEP Sites

The nine MOFEP sites are located in Shannon, Reynolds, and Carter Counties, which are about 84% forested (Hahn 1991). Agricultural activities are limited to bottomland corridors along primary streams. The research area consists of upland oak-hickory and oak-pine forest communities. Dominant tree species include white oak (*Quercus alba* L.), black oak (*Q. velutina* L.), post oak (*Q. stellata*

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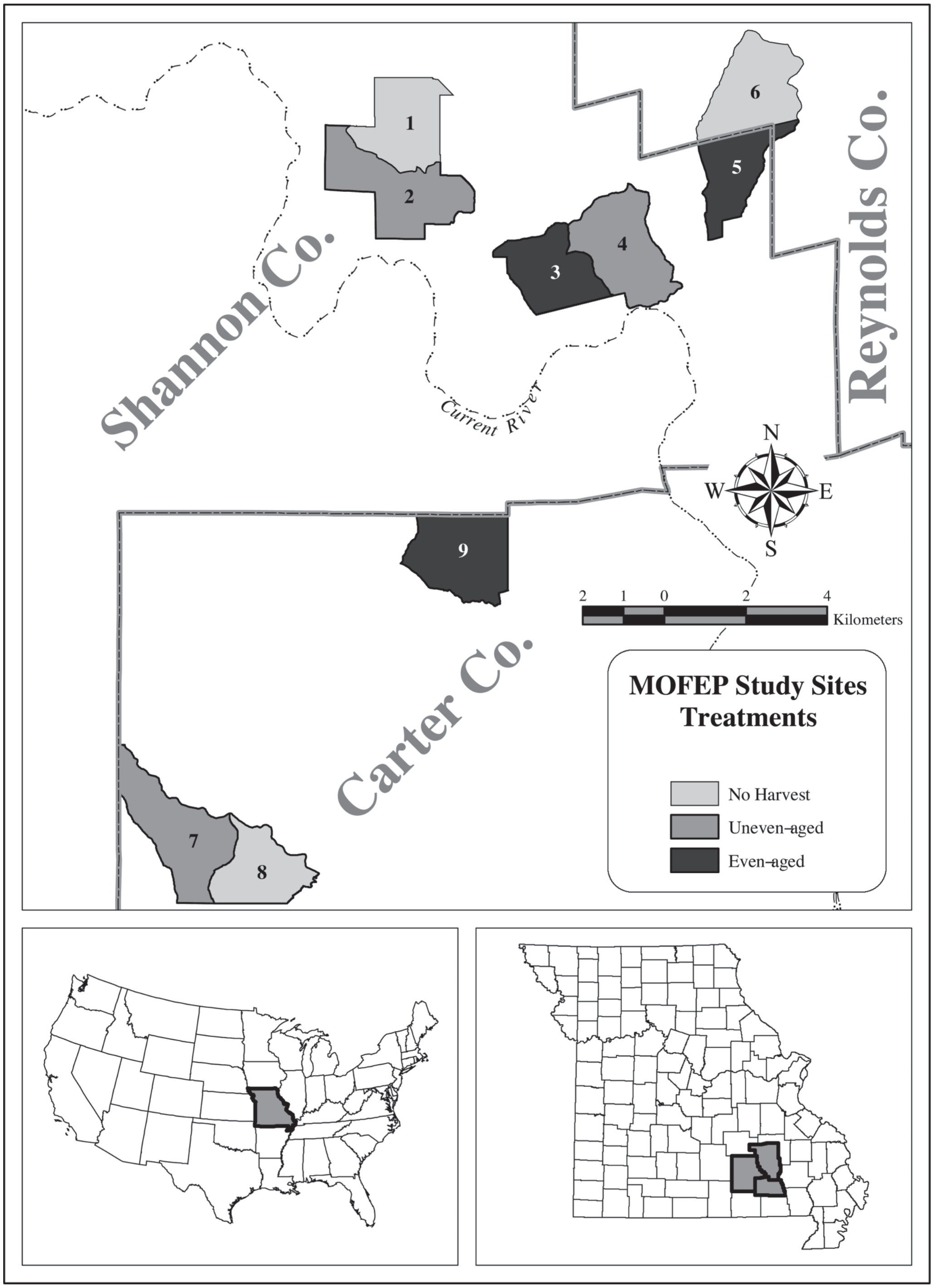

Figure 1. Location of the nine MOFEP sites and their assigned treatments.

W.), scarlet oak (*Q. coccinea* M.), blackjack oak (*Q. marilandica* M.), chinkapin oak *(Q. muehlenbergii* E.), shortleaf pine (*Pinus echinata* M.), and hickory (*Carya* spp.). Understory species include dogwood (*Cornus* spp.) and blackgum (*Nyssa sylvatica* M.) (Xu et al. 1997).

MOFEP is located within the Current River Hills subsection of the Ozark Highlands Section. The Ozark Highlands is an assemblage of nearly level to deeply dissected plateaus comprised primarily of Odovician dolomites or sandstones. Soils are formed primarily in loess, hillslope sediments, and/or residium. Natural vegetation in addition to the oak-hickory and oak-pine forests includes woodlands, oak savanna, bluestem prairie and glades. The MOFEP sites are located in the Current-Black Rivers Breaks and Current-Eleven Point Hills Landtype Associations (LTA) (Meinert et al. 1997).

Treatments

Each site was subdivided into cutting blocks based on LTA. Each cutting block was composed of multiple forest stands. Each site will be entered multiple times over the 100-year course of the MOFEP project. The first timber harvesting began in May 1996 and concluded in Nov. 1996. Slashing and follow-up work continued until Apr. 1997. The uneven-aged sites (UAM, numbered 2, 4, and 7) were marked according to MDC guidelines to achieve a target or guiding curve with a q of approximately 1.5 for 2- in. diameter classes to a maximum of 20 in. (Law and Lorimer 1989). In the uneven-aged treatment, trees were marked across all size classes; however, only trees 10.0 in. dbh or larger were tallied for volume. Group openings, "mini regeneration cuts," also were distributed throughout forest stands. All marked trees greater than or equal to 10 in. dbh were harvested or girdled. This treatment follows published MDC Forest Management Guidelines (Missouri Department of Conservation 1986).

In the even-aged treatment sites (EAM, numbered 3, 5, and 9), some forest stands were marked as intermediate harvests (sometimes called "thinnings"). An intermediate harvest was designed to release good growing stock in stands that were considered too young for an even-aged harvest. Older stands were regenerated by an even-aged harvest (sometimes referred to as "clearcuts" or "regeneration harvests"). All hardwoods greater than or equal to 10 in. dbh were harvested or girdled. All hardwoods trees less than 10 in. dbh were slashed after the even-aged harvest. No shortleaf pine or den trees were cut in the even-aged harvest.

All sites will be re-entered on a 15-year cycle. Individual stands in the even-aged sites will be on an approximately 90-year rotation with intermediate harvests. This is consistent with MDC practices and with much private land management in Missouri (Missouri Department of Conservation 1986). Between one-third and one-half of the stands in the uneven-aged sites with be treated every 15 years, depending on available volume (Sheriff 2002). These guidelines may change over the 100-year course of the MOFEP project as MDC refines its public land management practices. Our simulation treatments followed the same guidelines to the extent possible using software that requires a predetermined scenario.

Methods

We used the Landscape Management System (LMS) (see www.lms.cfr.washington.edu/) and the Forest Vegetation Simulator (FVS) (see www.fs.fed.us/fmsc/fvs/index.php) with FVS equations appropriate to the Missouri Ozarks to simulate forest growth 100 years into the future, based on forest plot data collected as part of the overall MOFEP project. FVS was developed by the United States Forest Service (USFS) and is their standard forest growth model, with variants available for many regions of the country. This model is a single-tree distance-independent model and was not originally designed to predict uneven-aged forest stands (Wykoff et al. 1982). LMS is a software package designed to help foresters manage and "grow" large data sets, using FVS or other growth models (McCarter et al. 1998). To date, 21 variants of the FVS model have been developed including a Central States variant based on previous work with the TWIGS and STEMS forest growth models (Miner et al. 1988). The Central States variant was used in the current analysis. LMS includes several harvest algorithms for even-aged treatments but none for uneven-aged treatments. We used the standard LMS algorithms to simulate the even-aged treatments and developed new algorithms to simulate the uneven-aged management as practiced by MDC on MOFEP. FVS treats regeneration and mortality exogenously, that is as coming independently from outside the model, and LMS allows users to input "lists" of ingrowth. We also developed or adapted regeneration models appropriate to the three treatments and determined mortality and growth modifiers for use in our simulations. Initial FVS simulations were made using the no-harvest stands, and the resulting mortality estimates were compared with actual mortality found on plot remeasurements taken from the MOFEP plots. Based on the higher actual mortality found on the plots, we adjusted the mortality multiplier (MORTMULT) in the FVS model. The Central States variant of FVS is known to underestimate actual mortality. However, the model does have the flexibility to modify mortality based on actual circumstances found in the field (David Larsen, University of Missouri).

When simulating growth and harvest on many forest stands simultaneously, data organization and management is usually difficult. Two approaches have been developed to help deal with large data sets. The USFS has developed a system (SUPPOSE) that deals with lists of inventory plot data using batch processes. This approach can be very helpful when processing inventories but is less friendly to forest managers focusing on forest stand management. A stand-based approach was developed by the University of Washington Silviculture Laboratory to process management units through several programs, including FVS. Both of these software packages are available through the Internet. We chose to use LMS in this study because the data are stand based and organized in management units.

FVS is designed as a single-tree, distance-independent forest growth model, and as such, stand density measures are averaged for the stand. As a result, forest treatments that produce an irregular spacing will not be correctly projected for individual trees but, on average, may come quite close (Wykoff et al. 1982). Earlier attempts to project the MOFEP treatments using the FVS model used a prewritten LMS treatment algorithm to simulate the actual treatment (Larsen 1997). The no harvest and even-aged treatments could easily be accommodated within the existing model. In the earlier phase of analysis, proportional thinning was used to simulate uneven-aged treatments. This reduced all diameter classes equally, so that if stands already had an uneven-aged structure it would be maintained but if the stands were not already uneven-aged this simulated treatment would not move the stand into an uneven-aged structure.

For this study we developed an uneven-aged treatment algorithm that would produce uneven-aged structure regardless of the initial stand structure. A depletion curve thinning algorithm was developed for the first entry in which each stand of trees was organized into diameter classes and trees over the desired or target number for the class were removed by the algorithm. Subsequent re-entries used proportional thinning to maintain uneven-aged structure. This algorithm was designed to match the actual MOFEP field treatments.

Initial conditions

The average size of a stand on the MOFEP sites was approximately 16 ac (Brookshire and Dey 2000). The initial standing volumes on the three MOFEP treatments were not significantly different from each other. The initial value (stumpage estimate) of the standing timber on each treatment was also similar (Table 1).

Simulated Treatments

Growth and yield simulations on the MOFEP sites were projected 100 years into the future, based on data from the initial MOFEP plot inventory in 1992. Crews collected data on all trees 4.5 in. dbh and larger on 648 $^{1}/_{2}$-ac plots. Each plot also contains 4 1/20 acre subplots on which all trees between 1.5 and 4.5 in. dbh were inventoried (Brookshire et al. 1997). The stands in the MOFEP study were simulated following the initial stand prescriptions determined in the field in 1996.

MOFEP sites received simulated treatments using each of the three silvicultural systems. The no harvest treatments consisted of simply growing the stand in the model for a period of 100 years. FVS' mortality model, with the appropriate mortality multiplier determined by plot remeasurements, was used to remove trees from the stand.

The even-aged treatments (EAM) were simulated by randomly assigning stands to groups and developing a schedule of intermediate harvests (thinning) and even-aged harvests for each group based on the actual MOFEP treatment plan for the next 100 years (Brookshire et al. 1997, Sheriff 2002, Sheriff and He 1997). In this silvicultural system, stands also had mortality removed and, at even-aged cuttings, ingrowth trees were added based on predictions from the ACORN model (Dey et al. 1996). Three typical ingrowth scenarios (high, average, and low) were developed and randomly assigned to specific stands, using Dey's probabilities. As on the real MOFEP sites, stands were on a rotation of approximately 90 years, with intermediate harvests. Every 15 years the sites were entered and those stands scheduled for harvest or thinning were treated.

Table 1. The initial volume (BF/acre) and timber value per acre by treatment for even-aged management (EAM), uneven-aged management (UAM), and no harvest sites. *N* is the number of stands in each treatment. Standard deviations are also shown (in parentheses) for the volume and value columns.

Treatment	Initial volume	Value	*N*
No harvest	5,723	$884	185
	(2,553)	(424)	
EAM	5,946	$910	207
	(2,584)	(414)	
UAM	5,365	$819	198
	(2,376)	(372)	

The uneven-aged treatment (UAM) required the most effort to simulate. We developed an algorithm that mimicked the actual MOFEP UAM treatment (see above) to thin specific diameter classes to the required number of trees determined by the target *q* factor at the first entry. This is a rather strict implementation of the q-thinning rule and produces heavy thinning when the initial forest structure diverges from the target forest structure. Regeneration also was input at an intermediate level to simulate the amount of regeneration actually observed on MOFEP plots (Kabrick et al. 2002). Because FVS is a distance-independent model, group openings were not simulated. Following the actual MOFEP plan, approximately one-third of the stands were available for treatment after each 15-year period. Stands were treated if there was sufficient volume for harvest.

Table 2 lists the entry years (for both even- and uneven-aged treatments) and the number of stands scheduled for each treatment in each year.

Results and Discussion

A total of 590 stands were analyzed by simulating their growth and yield for 100 years. For our economic analysis, a 100-year proved to be sufficient, as discounted future values approached zero over longer periods. The simulation produced stand statistics that are reasonable and within the range of expected outcomes for the region, given site quality and forest type. As stated earlier, the simulation software easily accommodated the no-harvest and even-aged scenarios. The uneven-aged scenario took considerable development to achieve stand growth similar to long-term, uneven-aged plot data for the area. The purpose of our growth and yield simulations was to allow for an economic comparison of the outcomes of the three forest treatments. Although there may be different models that could better simulate one or another of the three treatments under investigation, we were compelled to choose one model that could adequately simulate all three. Using different models for each treatment would have meant that any differences in economic outcomes might have been attributable to the model, not to the treatment. FVS and LMS proved capable of handling each treatment. In addition, the Central States variant of FVS was developed using FIA data taken predominantly from Missouri.

Yield is defined as the cumulative total volume of timber harvested per acre plus the residual standing volume at the

Table 2. The number of stands scheduled for simulated treatment under even-aged management (EAM) regeneration harvest and thinning and under uneven-aged management (UAM) harvest.

Year	Total stands	EAM harvest	EAM thinning	UAM harvest
1997	151	33	60	58
2012	146	30	62	54
2027	140	36	58	46
2042	159	32	69	58
2057	145	29	62	54
2072	139	28	65	46
2087	151	33	60	58

end of the simulation. The yields (Table 3) from the three MOFEP treatments were not statistically significantly different from each other and were considered feasible for public land management in Missouri.

Based on these yields, a simple net present value (NPV) equation was used to determine the per acre value of each treatment:

$$NPV = \sum_{n=1}^{N} \sum_{t=1}^{T} \frac{1}{(1 + d)^t} p_n q_{nt}$$

where

NPV = Net Present Value of all current and future timber harvested,
n = 1, 2, 3, 4, . . . N are the species harvested,
t = 1, 2, 3, 4, . . . T are the time periods (years) when harvests are scheduled,
d = the discount rate,
p_{nt} = the price per unit of species n in year t, and
q_{nt} = the quantity of species n in year t.

Timber prices for Missouri at the time of the first harvest were taken from the MDC publication *Timber Price Trends* (Jones and Treiman 1998). We selected 4% as the discount rate (although other rates can be explored) and assumed that timber prices moved at the same rate as prices in the general economy (the consumer price index). We also assigned a NPV to timber standing (residual stand) at the end of the simulation using the same methods. [Note that this analysis makes the assumption that there is no difference over time in the stumpage price for or grade of timber from either silvicultural system.] In addition, using this NPV formula on the residual stands effectively limits our analysis to the 100-year period modeled rather than to an infinite time horizon. Currently, there is not a well-developed pulpwood market in Missouri and what market there is has diminished with the closure of the state's only two pulp mills. For this reason, pulpwood harvests and prices are not taken into account.

The NPVs of the EAM and UAM treatments were not statistically different from one another. The no harvest stands, unsurprisingly, had a projected net present value that was much lower, becaue no timber was actually harvested from these stands, all value coming from the residual stand. Table 3 shows the average values, volumes, and NPV per acre by treatment.

Conclusions

The simulations of growth and harvest for MOFEP show no significant difference for the long-term 100-year period between UAM and EAM, using economic criteria such as NPV, or using silvicultural criteria such as yield. Under the scenarios that MDC has developed for MOFEP, neither management system is more financially attractive than the other. The overall value of the three treatments, however, includes other uses such as recreation or nontraditional forest products, nonconsumptive uses, such as bequest to future generations, and amenity values, such as scenic beauty. Another important difference between the two active silvicultural systems considered in this article is that the MOFEP even-aged treatment impacts many more acres (nearly one-half the stands, see Table 2) with heavy equipment traffic every 15 years (either harvesting or thinning), whereas the MOFEP uneven-aged treatment enter only one-third of the stands every 15 years with the same heavy equipment. These values and differences must be considered by managers of public land since the NPV decision criteria alone may not be decisive.

This conclusion is the result of simulations using LMS and FVS software that is currently state-of-the-art, although our finding cast some doubts on the software's ability to fully simulate UAM treatments. Further development of software and algorithm is needed to fully explore all the differences between the two. For example, we were not able to explore any differences in timber grade. In addition, we have assumed that loggers and timber buyers will pay similar stumpage prices for timber from both treatments, which may be incorrect in either direction. Currently, many Missouri loggers are unfamiliar with UAM and may regard it as more difficult and thus be less willing to pay. Conversely, if UAM management becomes viewed as more sustainable or more "eco-friendly" by the public than EAM ("clearcutting"), they may be willing to pay a premium.

Objectives, other than income, are important in making forest management decisions. The challenge will lie in developing metrics that allow for the comparison of the

Table 3. Average volume (BF/acre), timber value (nominal dollars) per acre, and timber NPV/acre by simulated treatment. Residual volumes and values represent the timber standing at the end of the 100 year simulation. *N* is the number of stands simulated for each treatment. Standard deviations are also presented (in parentheses) for the totals columns.

	Harvest		Residual		Totals			
Treatment	Volume	Value	Volume	Value	Volume	Value	NPV	*N*
No harvest	0	$ 0	9,001	$1,312	9,001	$1,312	$10	185
					(3,193.5)	(462.4)	(3.5)	
EAM	7,125	$1,094	2,941	$ 455	10,066	$1,549	$320	207
					(3,673.5)	(576.2)	(335.6)	
UAM	2,928	$ 465	6,608	$ 973	9,536	$1,438	$263	198
					(3,379.9)	(504.3)	(297.1)	

NPV of future cash flows and the nonmarket values mentioned above. Further research should be directed at conducting public surveys that will elicit public willingness-to-pay for the whole bundle of costs and benefits associated with each treatment into the future.

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